

National Aeronautics and
Space Administration



Centennial Challenges Program Space Technology Mission Directorate

CubeQuest Lunar and Deep Space Centennial Challenges

Distance & Orbit Determination Method

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Navigation Artifacts Requirement



- Cube Quest Judges must be able to verify Teams' performance claims
 - Deep Space Derby: Communications from a range beyond 4 million kilometers
 - Lunar Derby: Achievement and maintenance of lunar orbit
- To enable the Judges to do their work, Teams are required to submit certain “Navigation Artifacts” to CubeQuest Challenge Judges
- JPL MDNAV Section will analyze the data and report results to Judges
- Details will be provided in this presentation



Navigation Artifacts Approaches



- Approach I: Teams may submit Navigation Artifacts based on data generated by DSN ground/tracking stations
- Approach II: Teams may submit Navigation Artifacts based on data generated by their own (or procured) communications ground/tracking stations



Approach I



- **I. Using DSN Ground Stations to Generate Navigation Artifacts**
- Teams may use NASA DSN services to generate Navigation Artifacts *if* the CubeSats have a DSN RF-compatible transponder
- DSN can “shadow track” CubeSat communications with 3rd party ground stations by monitoring CubeSat carrier signal
- Teams must coordinate shadow tracking plans with DSN so that DSN can collect the Navigation Artifacts
- Teams provide frequencies for X or S band uplink/downlink
- Teams provide CubeSat ephemeris files to the DSN in Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) format
- DSN delivers Navigation Artifacts to JPL MDNAV
- No charge for using DSN tracking services *if using the DSN strictly for the purpose of generating Navigation Artifacts*



Approach II



- **II. Using Non-DSN Ground Stations to Generate Navigation Artifacts**
- No requirement for CubeSats to have DSN RF-compatible transponders
- Teams provide CubeSat ephemeris files to CubeQuest Challenge Judges in Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) format
- Team (or tracking network operator) delivers Navigation Artifacts to CubeQuest Challenge Judges
- CubeQuest Challenge Judges forward Navigation Artifacts to JPL MDNAV



Communication Distance



- **A. Authenticate Claimed Communication Distance:**
- At minimum, Teams must provide at least one of the following (**Red** = Approach I or Approach II, **Blue** = Approach II only):
- 8 hours of 2-way Doppler tracking within 1 week of the claimed achievement
- 8 hours of 1-way Doppler tracking within 1 week of the claimed achievement, where frequency stability ($\Delta f/f$) is less than or equal to 10^{-12} over a 24 hour period
- 8 hours of simultaneous 1-way Doppler tracking from stations separated by at least 5000 km within 1 week
- 10 astrometric measurements spanning at least 2 days (e.g. collected over 3 nights) within 1 week



Lunar Orbit Achievement/Maintenance

- **B. Authenticate Achievement/Maintenance of Lunar Orbit:**
- At minimum, Teams must provide at least one of the following (**Red** = Approach I or Approach II, **Blue** = Approach II only):
- 2-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit
- 1-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit, where frequency stability ($\Delta f/f$) is less than or equal to 10^{-12} over a 24 hour period
- Simultaneous 1-way Doppler tracking for one orbital period from stations separated by at least 5000 km within 1 week (no stringent $\Delta f/f$ requirement)
- At least 20 astrometric measurements covering at least one orbital period within 1 week



Additional Specifications (1/2)



- Additional specifications on the Navigation Artifacts are:
- The predicted CubeSat trajectory during the tracking interval must be provided in CCSDS OEM format
- Tracking data must be provided in CCSDS Tracking Data Message (TDM) format
- Transmit/receive frequencies may be provided instead of Doppler shift data
- No radiometric ranging data is required
- If using Doppler data, it should have an accuracy of 1 mm/sec over a 60 second compression period; a minimum of one data point per minute must be provided
- 2-way Doppler may be reconstructed using telemetry instead of using a transponder



Additional Specifications (2/2)



- If the Team's CubeSat transponder signal is coherent, DSN can obtain 3-way tracking data if Teams provide the ground station location, uplink frequency, and transmission dates and times
- If the lunar orbit tracking data is not continuous due to occultations of the spacecraft, it should cover most of the orbit that is not occulted, and all of the data should be within 4 revolutions
- Astrometric measurements should be accurate to 1 arc-sec ($5 \mu\text{rad}$) or better, which can be done with a 30 cm telescope if the CubeSat has a laser
- Astrometric measurements should be roughly equally spaced, if possible
- Teams may provide additional data that they feel strengthens their case at their discretion